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WIND-INDUCED MOVEMENTS OF BEACH SAND AT PORTSEA, VICTORIA

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ABSTRACT: An attempt is made to monitor beach changes associated with wind-induced movements of beach sand at Portsea, Victoria. This reveals that given adequate wind strength and atmospheric aridity, a process of sand-layer levelling, arising from alternate drying of sand and activation of sand movement by wind, takes place within a favourable time span of the tidal cycle. The moving sand ending up in sinks may constitute a permanent loss unless intra-compartmental and inter-compartmental transfers of the beach sand are made good by feedbacks from the dune-dominated coastal hinterland and the swell-dominated offshore subsystem. Where recovery is not complete, the cumulative, though diminished, net loss of beach sand plays a significant role in both the spatial and the temporal distributions of sand on the beach.

Beach changes associated with wind-induced movements of beach sand have not been given the attention they deserve. Well-based observations are confined to coastal dunes and dune topography. Mobility of beach levels of aeolian origin is considered to lag behind. However, recognition of transport surfaces on the foreshore as sites of sand mobilization without significant change of sand level renders this assertion untenable. Moreover, relevance of sand movements by wind to beach sediment budget further calls for their investigation. The beach at Portsea, with ample catchment for sand and a multi-directional wind system, provides an adequate base for such study.

THE COASTAL ENVIRONMENT

The ocean coast of Portsea between Mt. Levy and Sphinx Rock (Fig. 1, Inset A), formed since the Post-glacial rise of sea level (Keble 1950), encompasses a sandy beach abutting a series of dune-capped cliffs and shore platforms cut in Pleistocene dune calcarenite (Bird 1975, 1977). Forming the coastal hinterland is an undulating terrain 30-40 m high (Fig. 1, Inset B). Its overlying Holocene dunes (Bird 1972) rest on a basement of calcarenite formed by the consolidation and cementation of older dunes (Bowler 1966). Deflation, periodically affecting the dune surface, which is now partly under scrub or grass, initiates sand migration and blowout development. The lack of spatial pattern in the asymmetry of some dune profiles points to less well-defined sand drift. Absence of surface drainage testifies to permeability of the dune sand and percolation of rainwater into the ground. This enhances backshore sand movement.

Part of the beach compartment (Fig. 1) has been chosen for monitoring wind action on sand. The beach material is calcareous sand derived from shelly organisms thriving in coastal waters to the south, and from eroded calcarenite cliffs and overlying dunes. Except where a berm develops, beach profiles rise landward at angles of 10-12° but occasionally flatten off to 6-8°. Where a hardened calcarenite layer persists seaward beyond the beach sand, remnants of dissected intertidal platforms and reefs are exposed at low water.

The coast is characterised by a microtidal swell environment (Davies 1972). Northerly and north-easterly winds are prevalent in autumn, winter and spring, while southerly and south-westerly winds are prevalent in summer. Westerly winds may blow throughout the year but easterly winds are weak and infrequent. Winds strengthen with passage of cyclonic depressions south of the Victorian coastline. Despite a high frequency of gales in spring and summer (Bowler 1966), the mean monthly velocities are the highest in winter (Maher & McRae 1964), being largely those of northerly winds. Running from west-northwest to east-southeast, the coast is affected by wave action associated with onshore southerly winds, a favourable fetch and offshore depth in excess of 18 m. The more significant impact of the wind system, in the present context, is its role in the spatial tranfser of sand particles. Thus, given sufficiently dry conditions and a widening sand surface associated with an ebb tide, the southerly winds may move sand from the foreshore to the backshore which, if not acting as a sink, may subsequently allow northerly winds to return particles to the foreshore. Some or all of these may end up in the offshore zone. The decrease in rainfall in summer favours such inducement of sand movement by the southerly winds.

MONITORING SAND MOVEMENTS

Sand-level changes were recorded simultaneously with wind data. A sector of the beach (Fig. 1), 120 m long and 40-50 m wide, was chosen that had relatively uniform internal and external parameters including sand source, beach face slope, beach materials, offshore profile, and backshore and dune hinterland configuration. Fifty-six wooden stakes, each 30 cm long and 1.25 cm in diameter, were placed in a network designed by random-stratified sampling. This design was modified to account for different zones such as lower intertidal, mid-intertidal, upper-intertidal, storm-wave and backshore, and also for variation in beach topography. The posi-

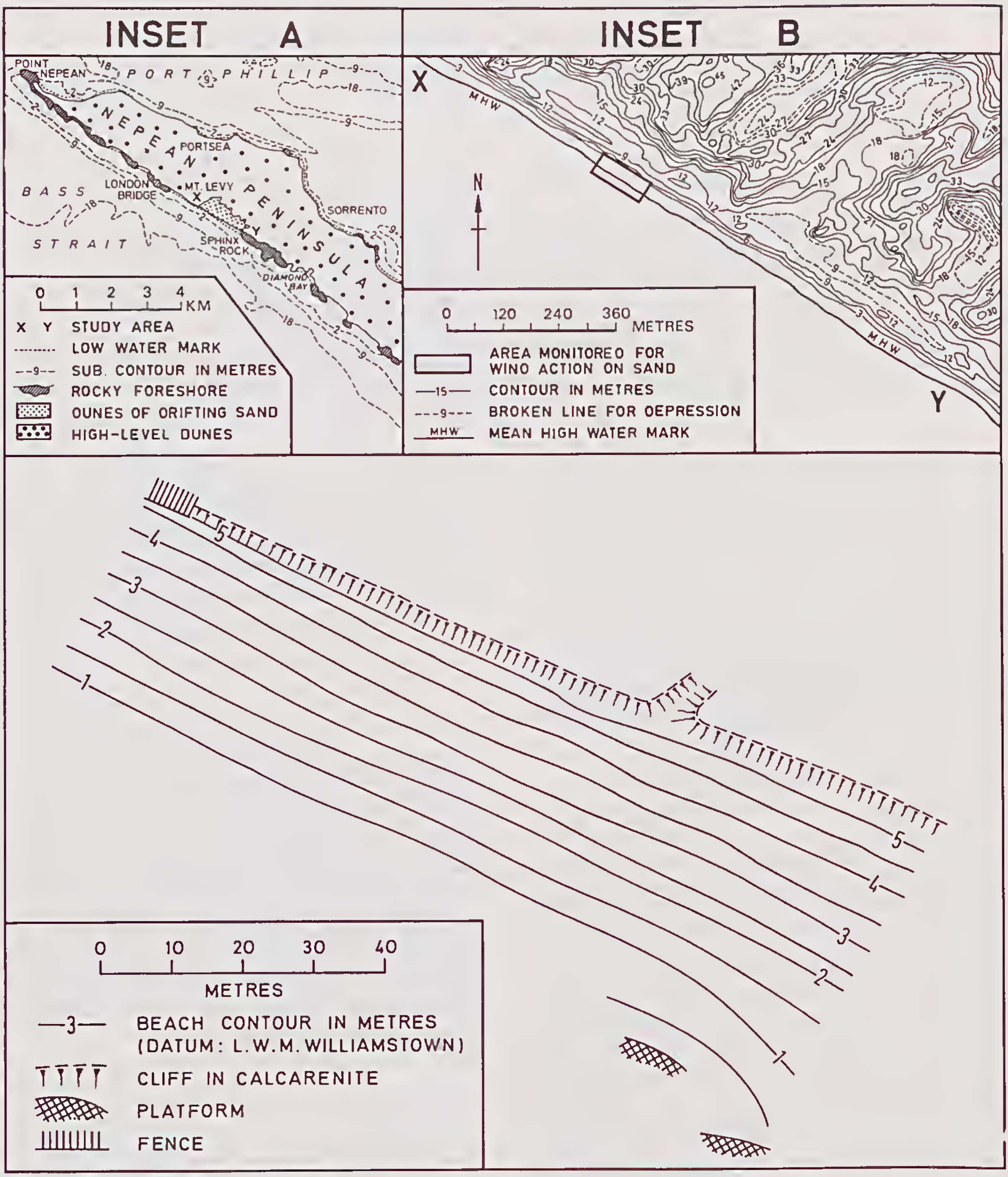

Fig. 1—Location of study area and shore-zone physiography at Portsea.

tion of the stakes was fixed by compass and tape and plotted on a base map, produced by levelling and tacheometry. Readings of sand levels were taken hourly over a six-hour period spanning where possible the second half of an ebb tide and the first half of the following flood. To collect sand moving in saltation or in creep, plastic sand traps 3.5 cm in diameter and 3.4 cm deep were used.

INTRA-COMPARTMENTAL AND INTER-COMPARTMENTAL TRANSFERS

Sand movement was found to be associated with winds above a critical force. A macroclimatic wind (Jennings 1957) of 46 km/hr with shear velocities up to 19 km/hr failed to initiate sand movement on 15 November (Table 1), but a macroclimatic wind of 44 km/hr with shear velocities of 19-22 km/hr started the process on 18

November despite the drizzle, pointing to threshold velocities of 19-22 km/hr required to move sand. With sand transport varying as the cube of excess of velocity over this threshold (Bagnold 1954), strengthening of wind offset the effect of rain as seen on 11 November. Raising the threshold velocity were salt crusts formed on the sand surface, reported on 25 November, and air dampness (Belly 1964), locally enhanced by splash and spray associated with plunging breakers.

Sand movement on 4 November 1977

Sand movement was localised in place and in time. The greater sand loss on 4 November than on 14 and 18 November (Fig. 2), taking place at low tide, was associated with strengthening of wind brought about by a passing, complex, low pressure system accompanied by a cold front. It took a subsequent drop in ground-level wind speed to below 19 km/hr, the onset of rain and increasing splash and spray with a rising tide to terminate the process. In the course of sand movement, phases of differential cut and fill were involved (Fig. 3) such that along rows EF and GH sand loss dominating the first two hours was then increasingly held up or replaced by gain. Hourly changes of beach levels (Fig. 4) revealed a change from dominantly falling sand levels, especially along profiles AB, EF and GH, to rising ones towards the backshore late in the monitoring period, pointing to intra-compartmental and inter-compartmental transfers of sand. Where the hourly sand levels merged together, transport surfaces occurred.

Nine of the ten sand traps operating at noon were filled by 1.00 p.m. More rapid infilling of those placed near the high water mark than those located down the beach pointed to sand migration from the lower-foreshore source region to the upper-foreshore receptor, overspill of which then effected inter-compartmental transfer. In size and rounding, the migrating sand in traps was comparable to those on the foreshore and in the blowouts, the only variation being its higher percentage of medium grains indicative of sorting effect. In respect of pivotability (Shepard & Young 1961) determined with a 'rock-and-roll' shape-sorter (Kuenen 1964), the sand displayed a better spread of values, and higher percentages of the more pivotable fractions, than the foreshore or the blowout sand.

Sand movement on 14 November 1977

Sand movement spanned half a spring flood tide and part of the following ebb. The reducing wind force, moist air persisting after rain, and abundant splash and spray generated by a rough sea cut down sand-level changes. Part of the upper intertidal zone and adjacent backshore became a receptor of the migrating sand (Fig. 2B). Elsewhere alternate gain and loss dominated (Fig. 3). The upper part of profile EF changed function from a transport surface to a receptor with overspill (Fig. 4) while gain in the upper part of the profile was concurrent with loss from the lower part, pointing again to intra-compartmental and inter-compartmental transfers of sand.

Sand movement on 18 November 1977

Covering the late stage of an ebb tide and almost entirely its succeeding flood counterpart, subdued movement of slightly wet sand took place under a narrow range in wind speeds and directions (Fig. 2C). This resulted in small cumulative changes (Fig. 3) and limited depth of disturbance (Fig. 4) of the foreshore. Profile EF showed limited change at the seaward end from 1.00 p.m. onwards (Fig. 4), a node of no change of the mid-tide level, and sand transfer from the lower to the upper foreshore.

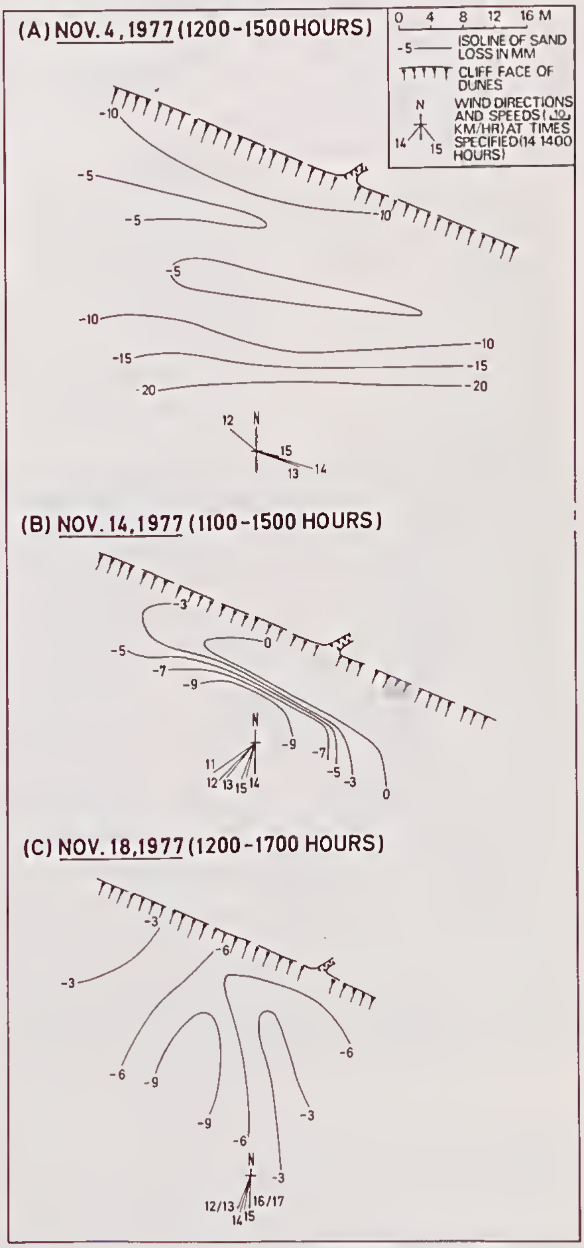

Fig. 2—Isolines of sand loss from Portsea Beach on 4, 14 and 18 November 1977.

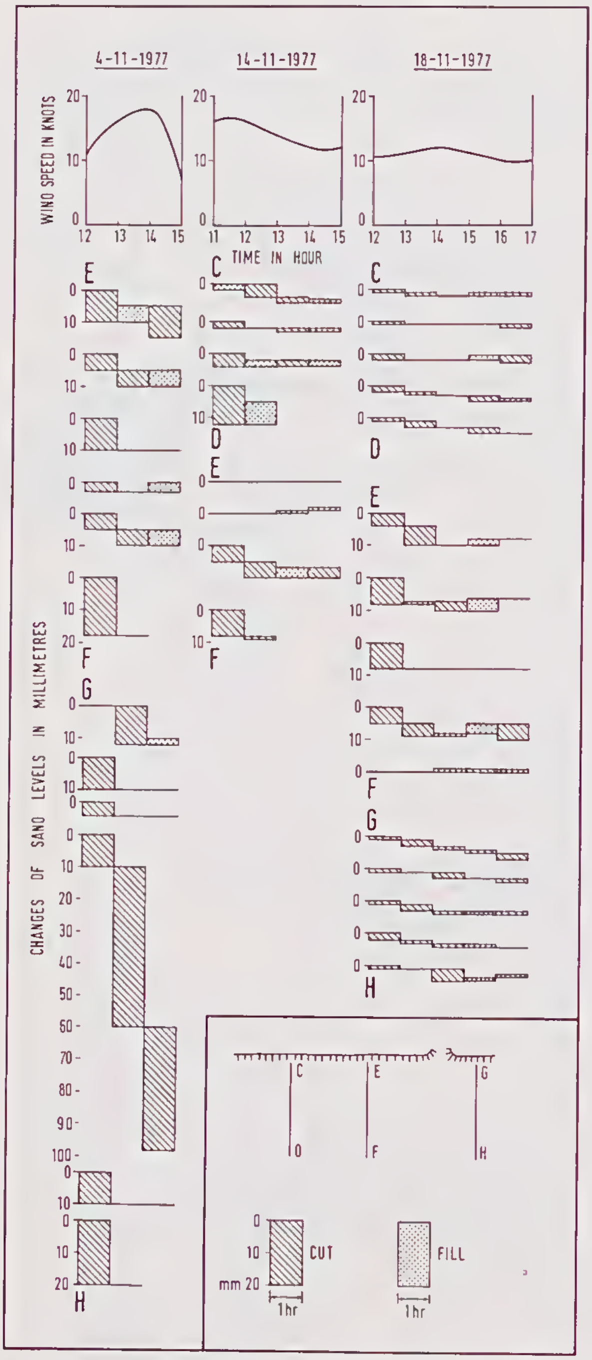

Fig. 3 — Cumulative graphs showing cut and fill at selected points on Portsea Beach on 4, 14 and 18 November, 1977.

Sand movement on 11 November 1977

To depict patterns of cut and fill, more sand traps were laid out to form a close network with the stakes used. Some cut was experienced (Fig. 5A) despite the fall of 2-3 mm of rain at Point Lonsdale (Table 1). Data on fill indicated the amount of sand passing over a transport surface. Its decrease in value landward from a peak (Fig. 5B) revealed substantial sand migration from source regions. Towards the back of the beach where the fill thinned out within the zero isoline for cut, there was a gain of sand.

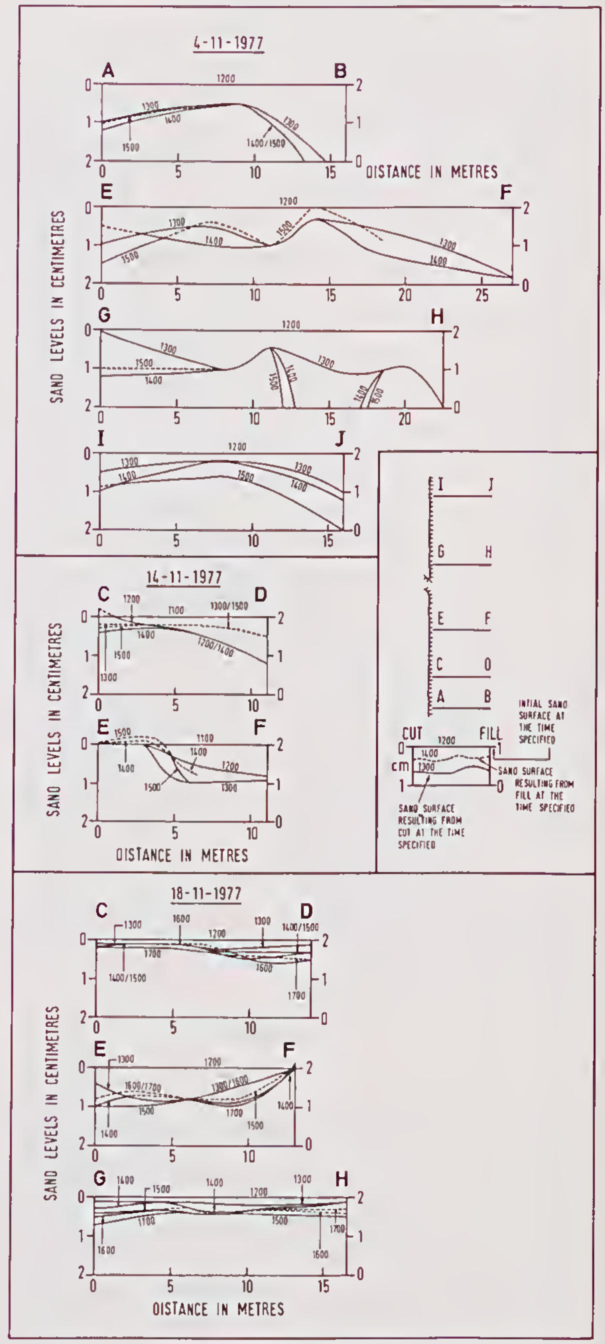

Fig. 4 — Hourly sand-level changes on Portsea Beach on 4, 14 and 18 November, 1977.

Table 1
Wind and Rain Conditions in the Period of Sand-Movement Monitoring

	Ground-level wind observations at site				Wind and rain observations at Point Lonsdale (9 km from site)					
					Wind				Rain (mm)	
					0900		1500			
	Date (1977)	Time	Direction	Speed (km/h)	Direction	Speed (km/h)	Direction	Speed (km/h)	0900	1500
With sand movement	Nov. 4	1200-1500	NW, ESE	13-30	WNW	72	N	44	Nil	0.60
	Nov. 11	1100-1330	SSW to SW	20-30	WSW	90	WSW	44	2.00	3.00
	Nov. 14	1100-1500	S to SW	22-30	SW	76	WSW	80	Nil	Nil
	Nov. 18	1200-1700	S to SSW	19-22	SSW	50	WSW	44	3.00	Nil
Without sand movement	Oct. 31	1245-1500	SSW to SW	12-19	WNW	11	SE	30		
	Nov. 8	1000-1500	S, SE	5-14	ESE	12	W	14		
	Nov. 15	1000-1500	S to SW	15-19	SW	46	WNW	32	Nil	Nil
	Nov. 17	1000-1500	SE to S	6-13	SE	30	E	16		
	Nov. 22	1200-1400	W to SW	6-9	S	12	WNW	20		
	Nov. 25	1000-1500	ESE to SE	7-11	E	36	ENE	34		

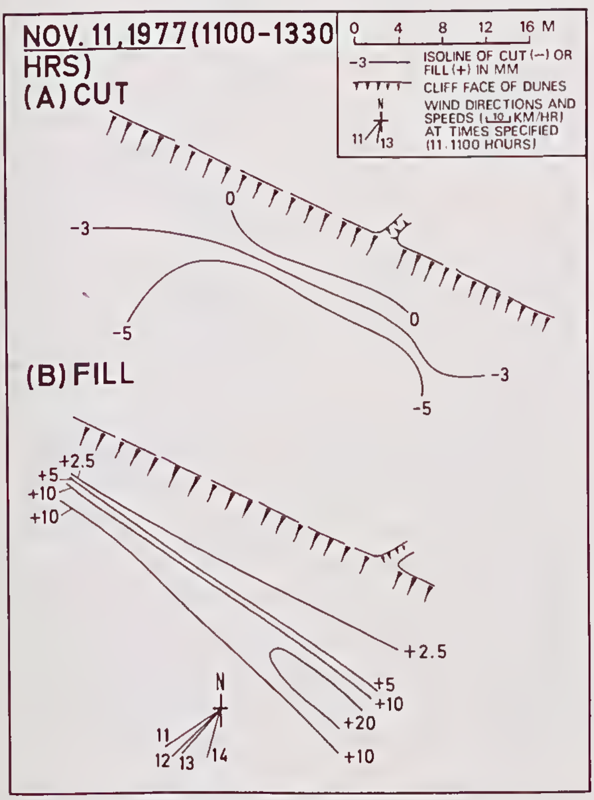

Fig. 5—Isolines of cut and fill of Portsea Beach on 11 November 1977.

Sand-layer levelling

Such intra-compartmental and inter-compartmental transfers of sand reflect deflation by wind action. This is tantamount to a process of sand-layer levelling in which removal of dry foreshore sand by wind, halted by the increasingly moist sand at depth, renews activity once the sand exposed at that level becomes sufficiently dry to be entrained. Alternate drying of sand and activation of sand movement by wind, preferably over a wide foreshore by spanning the latter part of an ebb tide and the first part of its succeeding flood, are held responsible for some loss of foreshore sand. Despite atmospheric drying of the upper foreshore for a relatively long period, the lower foreshore on the upwind side of an onshore wind witnesses maximum sand loss. This may be made good during the next flood tide or sustained during the following ebb. Thus, mainly by saltation and surface creep, sand moves inland and onto the coastal hinterland. Unless return of sand is effected by reversals of wind directions, the resultant sand deposition, often by accretion and to some extent by encroachment, is such that to the lower foreshore sand, the upper foreshore, the backshore and to some extent the coastal hinterland act as interceptors, receptors and sinks.

A wind simulation experiment carried out on samples of foreshore and blowout sand in the laboratory reveals a threshold in the percentage of sand moved when wind speed increases from 15 km/h to 19 km/h with the blowing time kept constant at eight minutes (Table 2). Further increase in wind speed with substantial reduction in blowing time increases the percentage of moving sand.

TABLE 2
RESULTS OF LABORATORY SIMULATION OF WIND ACTION ON SAND

Simulated wind action		% of simulated moving fraction	
Wind speed (km/h)	Exposure time	Foreshore sand	Blowout sand
15	8 min.	2.88	2.59
19	8 min.	44.30	64.48
22	30 sec.	52.28	52.00
26	10 sec.	71.59	65.98
30	5 sec.	79.06	75.13

DISCUSSION

Wind-induced movements of beach sand at Portsea have to be viewed in perspective if their impact on the spatial distribution and redistribution of sand and on the long-term sand budget of the beach is to be appraised. The primary movement, intra-compartmental transfer, is influenced by numerous local factors. Lenses of moistened or compressed grains resist wind action. The size of sand particles determines the ease with which the grains can be entrained. Shell or pebble layers present impose frictional effect on creep and inhibit sand movement where they survive instabilities and turbulence they help to create in the wind. Subsurface irregularities exhumed in the course of sand movement provide local base levels for deflation. The same is true of water tables of the beach although Portsea is relatively free from the impact of a raised water table associated with excessive seepage or inability of streams to maintain open channels to the sea. Periodic splash and spray accompanying plunging breakers or strong onshore winds, and obstacles, hollows or wet surfaces created by man on the foreshore, curtail sand migration.

While ridges and swales temporarily halt sand movement or channel it into pathways through windward scour and leeside accumulation giving patterns of cut and fill not readily explained in simple spatial terms, sand transfer from the lower to the upper foreshore is largely independent of beach gradient, profile or curvature. The extent of intra-compartmental transfer of sand is determined by the net catchment made available by an expanding or contracting foreshore associated with ebb or flood. It also varies with the nature and direction of winds. Locally, conditions range between increase in catchment associated with offshore, relatively dry northerlies in an ebb tide and decrease in catchment associated with onshore, relatively moist southerlies in a flood tide. In the former case, transfer of sand from the upper to the lower foreshore covers a catchment encompassing the backshore. The resultant inter-compartmental transfer not only returns sand from backshore receptors to the foreshore compartment, but also causes much sand to be lost to the offshore zone, especially with a spring ebb tide. In the latter case, transfer of sand from the lower to the upper foreshore by onshore, moist wind lags behind, especially with a contracted catchment associated with a flood tide. Between these extremes occur many catchments of intervening sizes representing different combinations of wind directions besides north and south, varied moisture content of the wind, and tidal states other than spring tides.

In such circumstances, sand movement operates along a number of pathways. With onshore wind of adequate strength in an ebb tide and dry conditions, deflation brings about surface erosion of the beach but may be held up by a subsurface shell or pebble layer (Fig. 6). Whether beach erosion undergoes or by-passes this negative feedback loop, it reduces the amount of beach material on the foreshore and the beach gradient. This permits deposition in the following flood tide should material be made available for deposition, helping to replenish the beach materials previously lost. Surface erósion of the beach through deflation, bringing about intra-compartmental transfer of sand in the foreshore subsystem, provides a link to the backshore subsystem through its supply of sand from an enlarging catchment to the backshore, thus initiating inter-compartmental transfer of sand (Fig. 6). Increasing the sand cover of backshore dunes thickens the loose sand mantle which in turn encourages sand removal by an onshore wind. Where a sizable transgressive sand sheet under a strong onshore wind makes available to the backshore sand in quantities too large to be trapped and fixed by the limited vegetation present, conditions are especially conducive to spilling of sand inland. Removal of sand by an onshore wind thus deprives the dune cover of a sand supply and impoverishes sand deposition on the backshore, imposing on the backshore in the long run a limit to sustained deposition (Fig. 6). Sand lost by the backshore, under unidirectional transport characteristic of wind action, is then either stored up temporarily in a catchment of the coastal hinterland or permanently lost to a sink.

The development of events as shown in Fig. 6 depicts the tendency for intra-compartmental transfer of sand, and backshore deposition arising from inter-

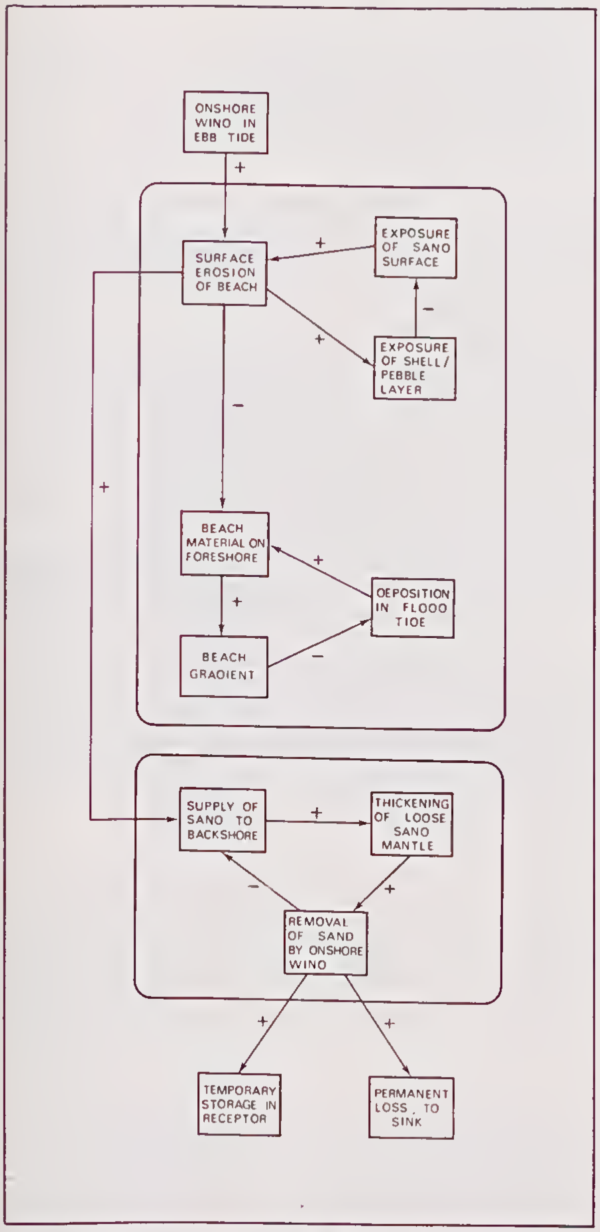

Fig. 6—Model showing the effect of onshore winds on the foreshore and the backshore in an ebb tide.

compartmental transfer of sand, to be self-arrested to some extent should conditions required for the feedback mechanism to work be made available so that the foreshore's loss is not always the backshore's gain. This confines the function of the backshore to that of a transport surface serving the coastal hinterland. The model presents the operation of processes associated with an onshore wind during an ebb tide. A flood tide imposes on the functioning of this system a contracted foreshore relative to the backshore, cutting down the catchment for sand supply and eventually reducing inter-compartmental transfer.

A change in wind direction gives the situation a face-lift. Combination of an offshore wind with an ebb tide turns the backshore, now on the upwind side, into a catchment and feeder of sand. Substantial movement of sand on the backshore, unless self-arrested to an appreciable extent through exposure of the indurated dune surface, sustains inter-compartmental transfer of sand to an expanding foreshore and receptor provided by a retreating tide, and the backshore's loss is the foreshore's gain except where the moving sand ends up in the sea. It takes the next flood tide to turn the bulk of this receptor into a sink, to cut short transfer of sand from the backshore by diminishing the foreshore, and to cause much sand gained through inter-compartmental transfer from the backshore to be moved to the offshore zone, imparting to the foreshore the mere role of a transport surface.

Broadly along these lines of action, the beach at Portsea, dominated by onshore southerlies in summer and offshore northerlies in winter, experiences differential transfer of sand in and across its compartments with every fluctuation of wind components and variation of the tide. Alternations of onshore and offshore winds over a relatively large time span are superimposed on the more regular cycles of ebb and flood of the tide occupying relatively small intervals on the time scale. Response of the beach to such external adjustment of changing process parameters is likely to find expression in a range of changes between two poles. On one hand, intra-compartmental and inter-compartmental transfers of sand, operating in association with onshore southerlies and under conditional self-regulation, make themselves felt, on a gradually diminishing scale with a change from ebb to flood tides, in the provision of fill to the backshore at the expense of cut on the foreshore. On the other hand, in another changing phase from ebb to flood, intra-compartmental transfer of sand imposing a cut on the backshore, and inter-compartmental transfer effecting a fill to the foreshore in association with the offshore northerlies hold sway. Whatever combination of process parameters prevails in association with one of these situations, the general tendency is for much moving sand entrained by wind to end up in sinks outside the foreshore subsystem and to some extent the backshore subsystem. This constitutes a permanent loss unless and until such intra-compartmental and intercompartmental transfers of the beach sand are made good. Feedbacks induced by wind action from the coastal hinterland dominated by dunes, and their counterparts induced by wave action from the offshore zone dominated by swell, may contribute towards this. Where the recovery process is not complete, the net loss of beach sand, although it is relatively diminished in amount, is cumulative. It is likely to play a significant role in the spatial distribution and redistribution of sand on the beach in general, and in the long-term sand budget of the beach in particular.

CONCLUSION

This study reveals that given the optimal wind strength and a combination of favourable circumstances, marked changes of beach levels result from wind-induced intra-compartmental and inter-compartmental transfers of sand in a shore system. Such mobility of beach levels recorded over short-term observations points to the 'catastrophic' loss of sand within short periods. Part of the significance of this lies in its bearing on how far the magnitude of a process may over-ride its frequency as so far indications are such that any interpretation of the role of aeolian agents in a beach environment solely on the principle of uniformitarianism may be taken too far. In the functioning of a process-response system, the periodic encroachment of drifting sand on the backshore, or on the offshore zone as the case may be, reinforces the assertion that the catastrophic loss of sand is spasmodic in action but cumulative in effect, and that there is the tendency for it to play such a significant role in the spatial distribution and redistribution of sand in a beach environment as not to be readily ignored.

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